Everything Counts:

Multiplicity Measurements in High Energy Collisions

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QCD in the RHIC Era

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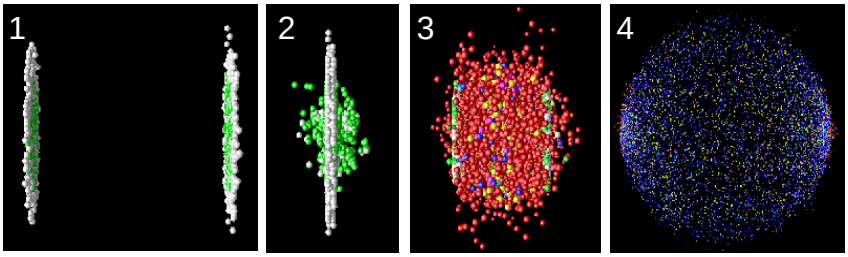
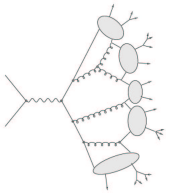
Heavy-Ion Collisions

VNI Simulations: Geiger, Longacre, Srivastava, nucl-th/9806102



Colliding Nuclei | Hard Collisions | Parton Cascade | Hadron Gas & Freeze-out

- Entropy produced as system evolves
  - Where does most of it come from?
  - Initial, partonic or hadronic stage?



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Multiplicity Measurements

Geometry

Impact parameter, Participants, Binary Collisions

Entropy Production

Stopping, Gluon production, Saturation, Fragmentation

Time Evolution

Formation, Expansion, Hadronic rescattering, Freezeout

If we can factorize the role of trivial **geometry**,
QCD can tell us about **entropy**,
if information survives **hadronization**

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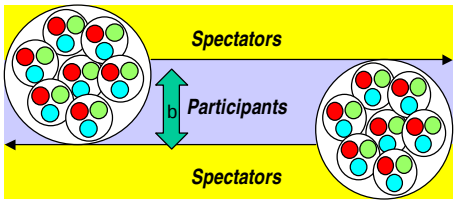
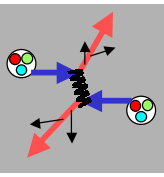
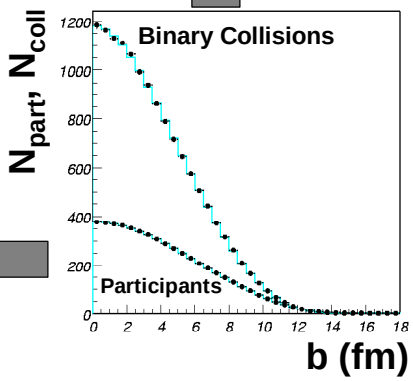
Geometry of AA Collisions



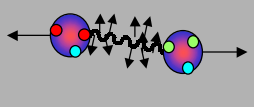
"Glauber" model of AA

Binary Collisions:
1. **Jet Production**
2. **Heavy Flavor**





Color Exchange:
1. **Soft Hadron Production**
2. **Transverse Energy**



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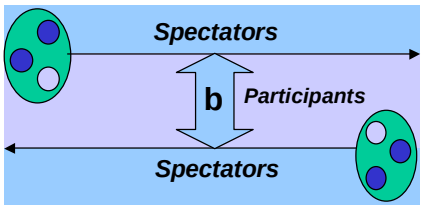
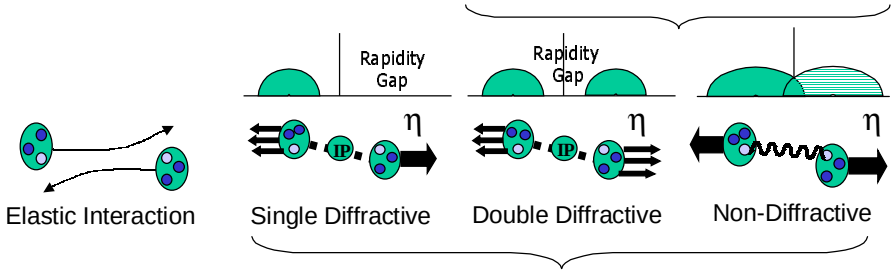
Geometry of pp collisions



Proton-proton cross section is also geometric: What do we use?

Non-single-diffractive (NSD) Collisions



Inelastic Collisions – slightly lower multiplicity!

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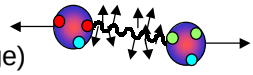
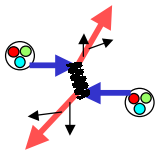
How should dN/dη scale?

- Two-component models
  (HIJING, KN,…)

Soft:
(color exchange)
wounded nucleons



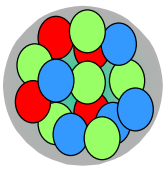
Hard:
binary collisions



$$\frac{dN}{d\eta} = (1-x)n_{pp}\frac{N_{part}}{2} + xn_{pp}N_{coll}$$

- Saturation Models
  (EKRT, KN, McLV,…)

At low-x, gluons recombine at a critical density characterized by "saturation" scale Q_s^2



$$Q_s^2 = \alpha_s\left(Q_s^2\right) N_g\left(x, Q_s^2\right) A^{1/3}$$

RHIC nuclear collisions are like eA collisions at HERA!

$$\frac{2}{N_{part}}\frac{dN}{d\eta} \propto \frac{1}{\alpha_s} \sim \ln\left(Q_s^2 / \Lambda_{QCD}^2\right)$$

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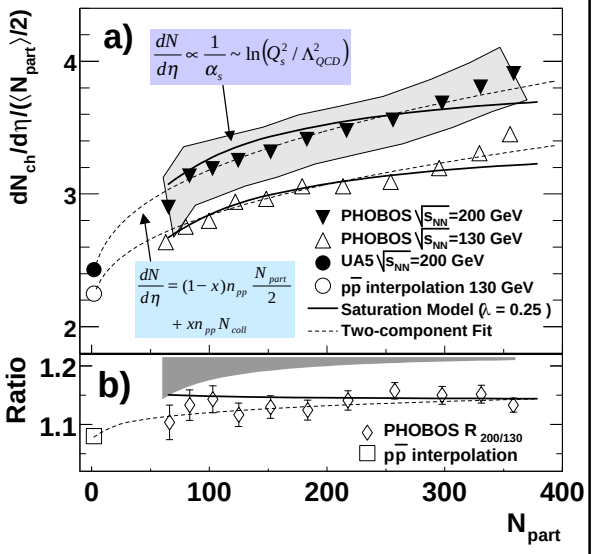
Two-component vs. Saturation

- Two PHOBOS measurements at midrapidity vs. energy
- 2-component fits use Glauber picture to interpolate between pp and central AA
  - x goes from .09 to .11
  - Predicted by minijet approach
- Saturation model also describes basic trend and energy dependence for N_{part}>60



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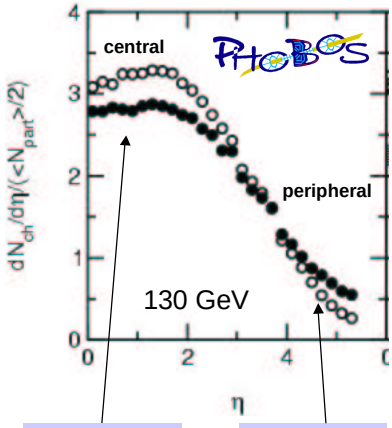
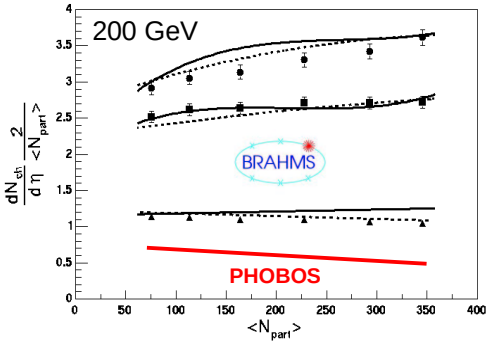
Scaling for |η|>0



- PHOBOS and BRAHMS observe similar centrality dependence vs. rapidity
  - Rises fastest at η =0
  - Slope decreases for high η
  - Crossover at η~y_{beam}-1.5



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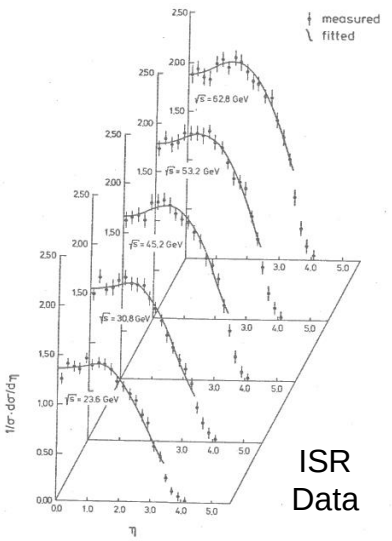
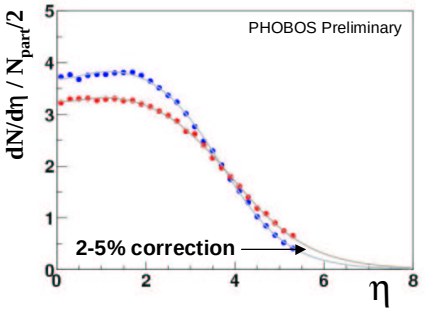
4π Multiplicity Distributions: $\langle N_{ch} \rangle$



ISR Data



$$\frac{1}{N_{part}}\frac{dN}{d\eta} = \beta\left(m, \langle p_T \rangle, \eta\right)\frac{C}{1+\exp\left((\eta - y_o)/D\right)}$$

Woods-Saxon + Jacobian lets us fit dN/dη distributions to get **total multiplicity**

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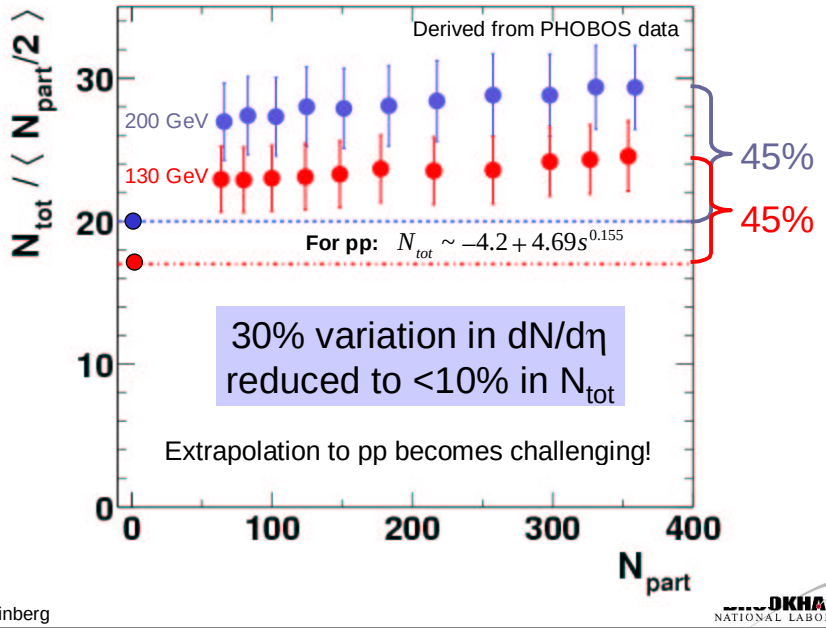
Scaling of Total Multiplicity



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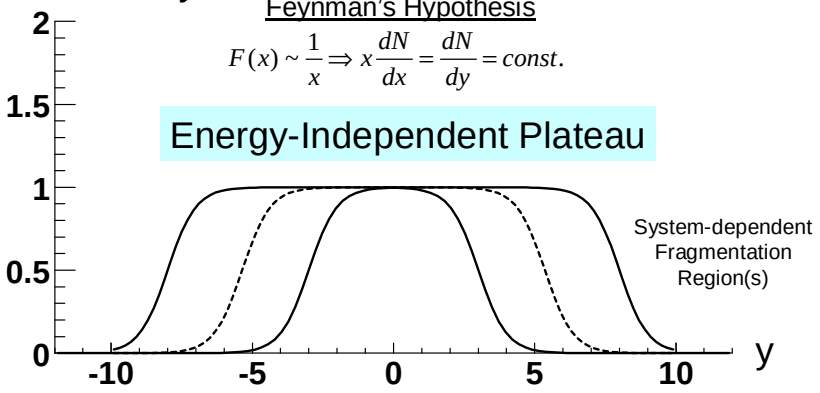
Shapes of Things

Particle Density

Feynman's Hypothesis

$$F(x) \sim \frac{1}{x} \Rightarrow x\frac{dN}{dx} = \frac{dN}{dy} = const.$$

Energy-Independent Plateau



Basic assumption of Bjorken hydro picture
(and thus much of the physics we like!)

And yet, we know xF(x)~1/x$^{\lambda}$ …

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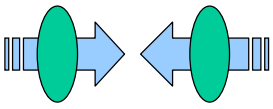
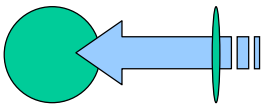
Limiting Behavior in pp

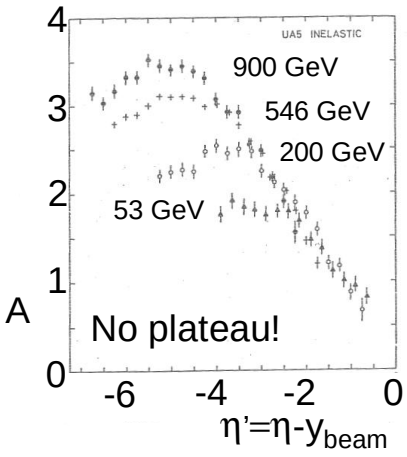


Center of mass

$y \rightarrow y - y_{beam}$



Target at Rest



$$\eta' = \eta - y_{beam} \approx \ln x_F - \ln\left(p_T / M_N\right)$$

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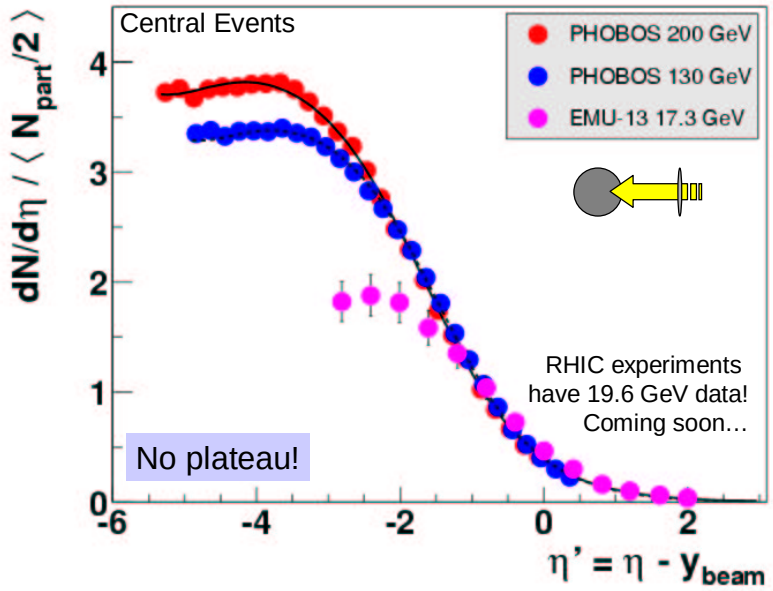
Limiting Behavior in Au+Au



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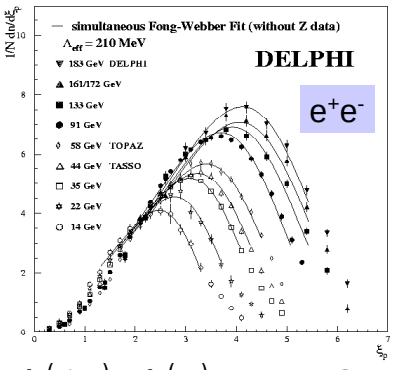
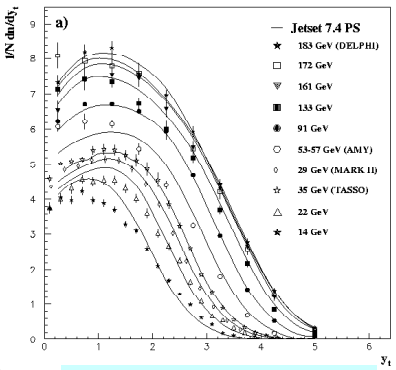
Limiting Behavior in e^+e^-

DELPHI, PLB459 (1999)





$$\xi_p = \ln(1/x_p) = -\ln(x_p) \sim y_{beam} - y + C = -y' + C$$

$$x_p = p/\sqrt{s}, \quad \xi_p^{peak} \sim 1/\alpha_s(s) \sim \ln s$$

All particles included, so ×2 relative to one side

Limiting behavior seen in e^+e^- at LEP

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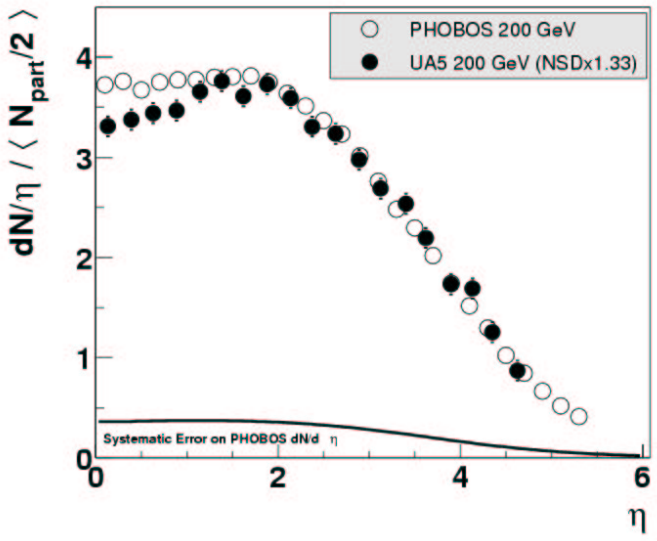
Recall: RHIC vs. SppS



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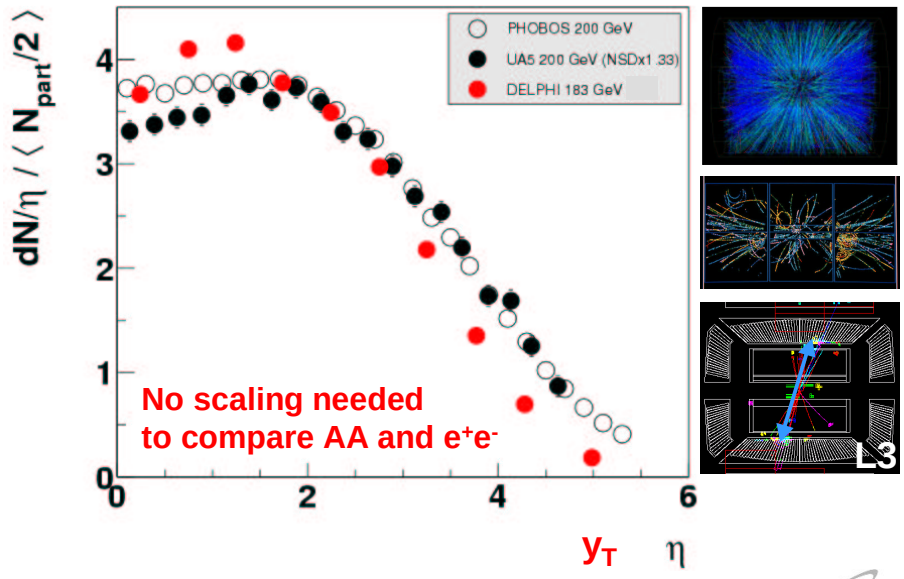
RHIC (200 GeV) vs. LEP2 (183 GeV)



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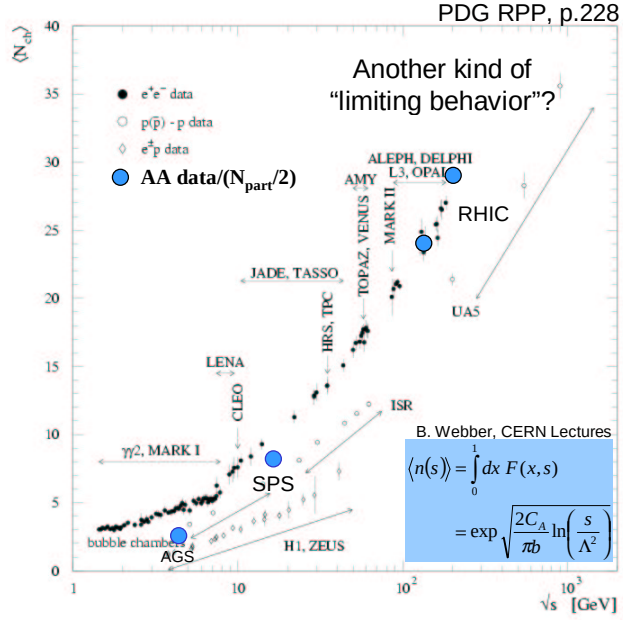
Total Charged: AA vs. e^+e^-

PDG RPP, p.228



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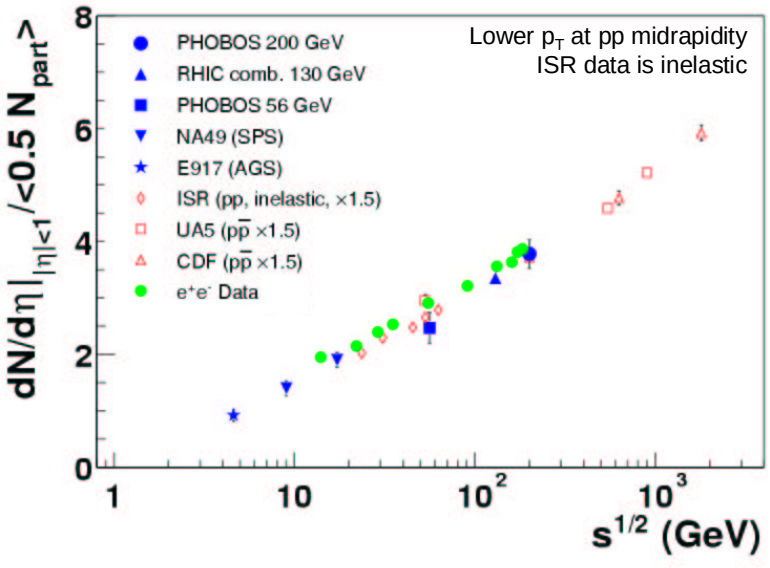
Mid-Rapidity Revisited



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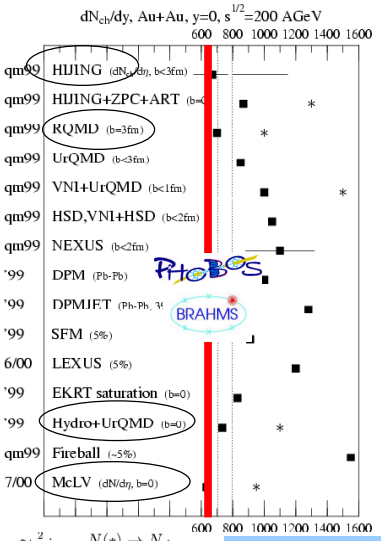
dN/dη: Theory

- 3 years ago (QM99) predictions varied by factor of 2
- RHIC results have landed solidly on the "low" side of prediction range
- Extrapolating QCD hard processes from pp overestimates charged particle production

Maybe we shouldn't try?…



Eskola, QM2001

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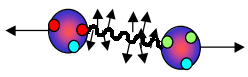
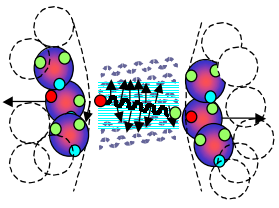
What does this mean? An idea:

- Wounded nucleons in pp collisions are constrained by leading particles
- In nuclear collisions, perhaps wounded nucleons are different?
  - Strings are "orphaned" from their parent nucleons
  - More energy for producing $\langle N_{ch} \rangle$
- Does e+e- help us understand aspects of AA collisions?
  - Entropy production is the same (is it a limit?)
  - Thermal fits get similar results for LEP & RHIC (Becattini et al)
  - Lots of problems! Strangeness? Flow? Jets?



pp



AA

$q\bar{q}$

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Conclusions & Questions

- 2-component geometrical interpretation seems to work only at mid-rapidity
  - Rest of particle production appears to be wounded-nucleon (but not exactly like pp)
- Universal limiting behavior seen in all QCD systems
  - AA, pp, e^+e^- ➡ $q\bar{q}$
- Simple energy scaling of N_{ch} observed
  - AA : e^+e^- : pp = 1 : 1 : 3/4
- Do AA collisions at high energy reach the limit of pure qq fragmentation?
  - Trivial, or accidental? ($\sqrt{s}$=56 GeV would be nice)
  - Should/would/could QCD *predict* this?

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